Effects of Precipitation on the Upper-Ocean Response to a Hurricane

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(Manuscript received 22 March 2006, in final form 22 June 2006)

ABSTRACT

The effect of precipitation on the upper-ocean response during a tropical cyclone passage is investigated using a numerical model in this paper. For realistic wind forcing and empirical rain rates based on satellite climatology, numerical simulations are performed with and without precipitation forcing to delineate the effects of freshwater forcing on the upper-ocean heat and salt budgets. Additionally, the performance of five mixing parameterizations is also examined for the two forcing conditions to understand the sensitivity of simulated ocean response. Overall, results from 15 numerical experiments are analyzed to quantify the precipitation effects on the oceanic mixed layer and the upper ocean. Simulated fields for the same mixing scheme with and without precipitation indicate a decrease in the upper-ocean cooling of about 0.2°–0.5°C. This is mainly due to reduced mixing of colder water from below induced by the increased stability of the added freshwater. The cooler rainwater contributes a maximum of approximately 10% to the total surface heat loss from the ocean. The rate of freshening due to precipitation exceeds the rate of mixing of the more saline water from below, leading to a change in sign of the mixed layer salinity response. As seen in earlier studies, large uncertainty exists in the simulated upper-ocean response due to the choice of mixing parameterization. Although the nature of simulated response remains similar for all the mixing schemes, the magnitude of freshening and cooling varies by as much as 0.5 psu and 1°C between the schemes to the right of the storm track. While changes in the mixed layer and in the top 100 m of heat and salt budgets are strongly influenced by the choice of mixing scheme, integrated budgets in the top 200 m are seen to be affected more by advection and surface fluxes. However, since the estimated surface fluxes depend upon the simulated sea surface temperature, the choice of mixing scheme is crucial for realistic coupled predictive models.

1. Introduction

Tropical cyclones represent one of the most destructive natural disasters known to mankind. The primary energy source driving these storms is the latent heat release due to the condensation of water vapor, which ultimately comes from the ocean. As a storm intensifies, increasing wind speed may increase evaporation and supply the storm with the necessary source of heat for further intensification. However, with increasing wind speed, oceanic vertical mixing reduces sea surface temperature (SST) causing a reduction of sea surface fluxes. Past studies have focused on this negative feedback as part of the spreading three-dimensional wake (Chang and Anthes 1978). Estimates of cooling induced by vertical mixing in the oceanic mixed layer (ML) heat budget have ranged from about 70% from observations (Jacob et al. 2000, hereafter JSMB) to as high as 99% in a coupled ocean–atmosphere model simulations (Bender et al. 1993). Additionally, prestorm ocean features such as warm core eddies and ocean currents also affect the upper-ocean cooling (Jacob and Shay 2003).

Understanding the impact of these factors in the mutual interaction of the tropical cyclone–ocean is central to more accurately forecasting intensity change in landfalling tropical cyclones (Marks et al. 1998). However,

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DOI: 10.1175/MWR3366.1

effects of precipitation on the upper-ocean heat and salt budgets during hurricane passage have not been investigated in detail in the past due to obvious measurement difficulties of rain rates in the inner core of tropical cyclones. Based on climatological rainfall estimates of Miller (1958) and average precipitation temperatures consistent with those found by Gosnell et al. (1995) in the western Pacific, JSMB estimated a 10% contribution to the heat flux by rain-induced cooling. However, the addition of fresh rainwater at a rate exceeding 15 mm h^{-1} into the ocean mixed layer will also significantly affect static stability and therefore modulate ocean mixing. Hence, in this paper, the effect of rainfall on upper-ocean heat and salt budgets is investigated using a high-resolution numerical model for forcing associated with hurricane Gilbert (1988) in the Gulf of Mexico for quiescent initial conditions. For five commonly used oceanic mixing schemes, the spatial evolution of mixed layer tracers is also examined to quantify the magnitude of variability. The paper is organized as follows: in section 2, details of the numerical model, initial conditions, forcing, and numerical experiments are presented, followed by the effects of precipitation on the upper-ocean heat and salt budgets in section 3 for different mixing parameterizations. Results are summarized in section 4. As the focus of this paper is on the precipitation effects, detailed evaluation of the mixing schemes and comparisons with data will be presented in a forthcoming paper.

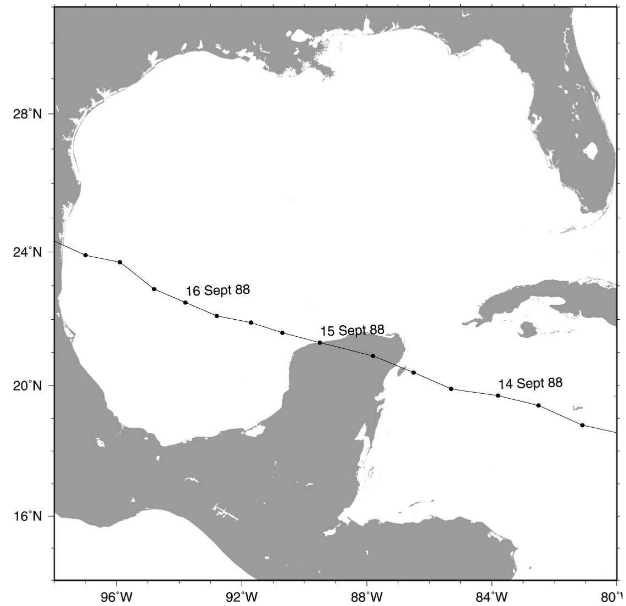

FIG. 1. Geographic area covered by the model domain. The solid line represents the track of the hurricane. Storm center locations every 6 h are denoted by the dots, and the dates for 0000 UTC positions are labeled.

4. Summary and conclusions

The hybrid coordinate ocean model initialized with quiescent conditions and configured in a Gulf of Mexico domain is used to understand the effects of precipitation on the upper-ocean response during a tropical cyclone passage. As the model has a choice of five different mixing parameterizations, sensitivity of the simulated response to these schemes is also investigated. Wind forcing associated with Hurricane Gilbert in the Gulf of Mexico along with derived precipitation rates based on satellite climatology provides the forcing conditions in these simulations. With the temperature of rainfall being the same as the mixed layer temperature, results indicate a small variability in the simulated MLT for four of the five mixing schemes considered. However, the results for the PWP scheme show a difference of more than 0.5°C. Although the MLT values in the precipitation forced cases are higher due to the freshwater-induced higher stability and the associated reduction in mixing, sensible heat loss due to colder precipitation temperatures does not have a large effect on the MLT. However, simulated MLS is more sensitive to the freshwater forcing. MLS without precipitation tends to be more saline with respect to prestorm values due to mixing from below whereas with added precipitation simulated MLS tends to be fresher. Similar to the MLT evolution, MLS in the PWP scheme is more saline due to enhanced mixing without precipitation that becomes comparable to other schemes when freshwater forcing is added. However, differences between results for the five mixing schemes are much larger than those induced by precipitation. While the momentum response is comparable between the schemes, surface fluxes to the atmosphere vary by more than 300 W m^{-2} between the schemes. This result highlights the need to evaluate the different mixing schemes in comparison with data to identify more appropriate schemes for use in coupled predictive models. Using ocean data acquired in three major hurricanes, these mixing schemes are currently being evaluated that will be the focus of a forthcoming paper.